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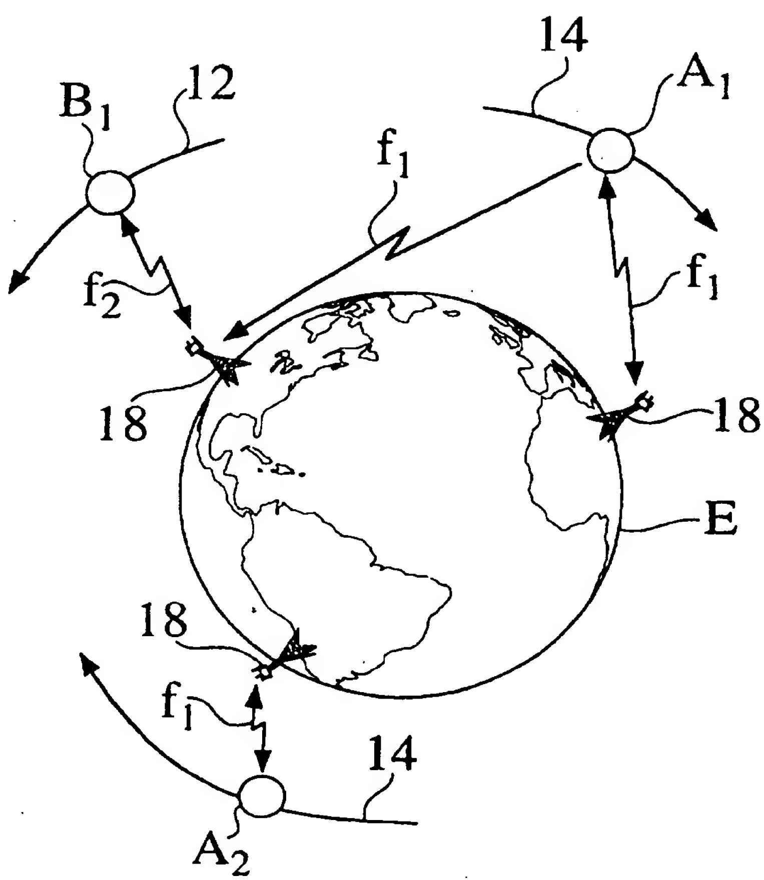
(54) Title: RADIO FREQUENCY SHARING METHODS FOR SATELLITE SYSTEMS

(57) Abstract

Methods and apparatus are disclosed which allow satellites (A1-M, B1-N) in a plurality of systems (A, B) to use the same radio frequencies (f1-n) with minimal interference. A timing algorithm is used that does not allow two satellites (Ai, Bi), "visible" at the same point on the Earth (E), to transmit on the same frequency (fi).



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Radio Frequency Sharing Methods for Satellite Systems

TECHNICAL FIELD

The present invention relates to the field of satellite communications and telecommunications systems. More particularly, this invention provides methods of frequency sharing for non-geostationary, store-and-forward, satellite communication systems.

BACKGROUND ART

The Increasing Demand for Telecommunications Services

Over the past few decades, the demand for access to information has increased dramatically. Although conventional wire and fiber landlines, cellular networks and geostationary satellite systems have continued to expand in an attempt to meet this relentless growth in demand, the existing capacity is still not sufficient to meet the burgeoning global appetite for telecommunications services.

Through technology advances and regulatory changes, mobile communication services were offered on a commercial basis and grew to meet city, regional, national and even international coverage needs through interconnection to public networks. As part of this evolution, wireless network standards have developed, on both a national and international basis, although there are still no truly international seamless wireless networks.

The decline in price of mobile services is one of the most important forces helping mobile communications reach broad-based markets and demonstrate rapid subscriber growth. The forces driving development of terrestrial wireless communications include advances in technology, declining prices and digital technology.

The resulting reductions in service and equipment cost attributable to the factors described above have allowed mobile communications to penetrate both business and consumer markets. The ultimate goal of wireless services is to provide two-way, ubiquitous and affordable communications services. It was only very recently, with the introduction of mobile satellite services, that this has been made possible. Indeed, mobile satellite services are the final step in the evolution of wireless communications service and are the only services which can provide this ultimate goal of ubiquitous wireless communication.

Terrestrial-Based Mobile Communications Services

Currently, there are five major types of public mobile communications services used throughout the world:

1. Cellular, which provides primarily two-way, interconnected voice service with mobile, transportable, and portable telephones and providing a platform for data transmission;

2. Paging, which offers primarily one-way data transmission of numeric and alphanumeric messages;

3. Private Radio/SMR, which supplies primarily two-way voice service to closed user groups, but may also provide interconnected and mobile data services. SMR is a subset of private radio where service is provided on a commercial basis to businesses by carriers instead of the businesses owning their own systems;

4. Mobile Data, which provides networks for the exclusive transmission of mobile data; and

5. Personal Communications Services (PCS), which uses microcell technology, includes a wide range of voice and data services, for example, one-way outgoing PCS services, called CT-2, licensed in several countries such as the U.K., Taiwan and the Netherlands.

The growth and evolution of mobile services show that subscribers migrate from basic limited services to more advanced services over time. The growth of terrestrial-based mobile services will increase the awareness and demand for enhanced mobile satellite services. Moreover, mobile satellite services will be able to provide service in areas that cannot be economically served using terrestrial networks.

Wireless Communications

As a result of the advances in technology, privatization, and decreasing prices on a world-wide basis, wireless communications have undergone a rapid increase in subscriber growth in the past several years. The result is that new enhanced wireless services tend to gain market acceptance more rapidly than did earlier wireless technologies. This phenomenon is attributable to the increasing functionality, value relative to price, and awareness among the population of each successive technology. Paging was introduced with only one-way, non-voice communications at a relatively high price. SMR provided two-way communications, but only within a closed user-group. Finally, cellular offered two-way interconnected voice with increasingly wide area coverage. The result of the rapid growth in wireless services worldwide builds an awareness and future demand for the benefits of advanced wireless communications.

Mobile Satellite Services

Mobile satellite services are uniquely positioned to complete the evolution of wireless services. These services offer ubiquitous coverage, interconnection with other networks and a variety of services.

Mobile satellites will be able to support both voice and data terminals, depending upon the particular need of the user. In general, however, voice service will be expensive relative to data, due to the greater infrastructure required for voice communications and the generally greater efficiency of data communications.

Several previous efforts to enhance world-wide communications capabilities are briefly described. Robert R. Newton discloses a *Multipurpose Satellite System* in his U.S. Patent No. 3,497,807. Newton describes a system in which "any point on Earth is always within the line of sight of some satellite and any satellite is always within line of sight of an adjacent satellite in the same orbital plane." Col. 2, Lines 4-7.

U.S. Patent No. 4,135,156 by Sanders et al., entitled *Satellite Communications System Incorporating Ground Relay Station Through Which Messages Between Terminal Stations Are Routed,* contains a description of a "satellite relay communications system" that "includes a ground relay station arranged so that each message from one subscriber to another is relayed by the satellite relay to the ground relay, processed by the ground relay and then transmitted to the second subscriber by way of the satellite relay." See Sanders et al., Abstract, Lines 1-6.

Paul S. Visher disclosed a *Satellite Arrangement Providing Effective Use of the Geostationary Orbit* in his U.S. Patent No. 4,375,697. His patent recites a "satellite squadron or cluster formation" which "is disposed in a predetermined location in...geostationary orbit...." See Visher, Abstract, Lines 1-2.

In their U.S. Patent No. 5,119,225, Michael Grant et al. explain their *Multiple Access Communication System*. The inventors describe a system that incorporates "a node spacecraft" in geostationary orbit that works in combination with "several user spacecraft" in low Earth orbit. See Grant et al., Abstract, Lines 1-3.

The references cited above disclose telecommunication systems that include satellites deployed in polar, Equatorial and inclined low Earth orbits (LEO). The systems provide for transmitting a message between two low-power fixed or mobile terminals on the ground through a store-and-forward network. The store-and-forward relay method takes advantage of the geometry of a system which allows the satellites to fly over different parts of the globe frequently. These LEO systems do not provide access to a satellite one hundred per cent of the time. In the most populated areas of the globe, a user may have to wait for many minutes until a satellite flies into view.

A burgeoning population of LEO communication satellites for commercial and military use is projected. Some observers estimate there will be 51 to 56 million users by the year 2002. To fill such a need for low-cost messaging and data communications available radio frequencies are required which may be packed into an already crowded very high frequency (VHF) and ultra high frequency (UHF) spectrum. Such spectrum already has many users.

Current satellite communication systems use different frequencies simultaneously to communicate between many satellites in the same constellation which are "visible" to a user on the Earth's surface. The term "visible" is an analogy which refers to the fact that radio energy at VHF and UHF frequencies travel essentially in line-of-sight directions. To prevent interference between a satellite to or from which a transmission is expected and other satellites in the same system requires that one satellite transmit and receive at a different frequency. Often the same frequency is used only for satellites in different orbital positions or orbital planes. This is so-called space division multiple access (SDMA).

Interference among multiple satellites "visible" at the same point on the Earth may also be prevented by operating different signals at different polarization, or by use of orthogonal spread-spectrum codes. Time division multiple access (TDMA) is a further method of preventing satellites in a particular constellation from interfering with communications by others in the same constellation. The same frequency may be employed by different satellites in the same constellation with overlapping radio beams, but only at different times.

The U.S. Federal Communications System (FCC) and the International Telecommunications Union (ITU) have historically based assigned frequency spectrum to non-geostationary satellites on an exclusive use basis. That is, once assigned to a system, the frequency spectrum is unavailable for assignment to others wishing to operate in the same service region. In some cases, assignment of frequency spectrum to a system comprising a single satellite would preclude further use of that spectrum world wide.

It would be a significant commercial advantage for a new system using a number of satellites to offer a user virtually immediate access to a satellite without interference. It would also be a commercial advantage, in some cases, to offer nearly instant, interference-free communication of the user's message to certain destinations. However, operation of numbers of new constellations of satellites presents a serious problem in that old constellations have been built and launched with little or no means of modifying their patterns of protection from communication interference. Therefore, providing a means, with minimum complexity, for spectrum sharing by new and older constellations would allow a significant increase in the available non-geostationary satellite communication services at lower cost than is presently possible.

The development of a system which would reduce or obviate interference between satellites of a new constellation and satellites of an already exiting constellation would constitute a major technological advance and would satisfy a long felt need in the satellite and telecommunications industries.

DISCLOSURE OF THE INVENTION

The current invention provides new methods for frequency spectrum sharing among satellites of a new constellation and satellites of an already existing constellation of non-geostationary satellites. For such satellites, potential radio frequency interference occurs at varying, but predictable times when satellite radio beams overlap on the Earth or satellites otherwise have conflicting regions of their coverage footprints. Two constellations of non-geostationary satellites have potentially interfering, overlapping coverage in many regions of the Earth simultaneously. Using the techniques of this invention, a new constellation of satellites can share frequency spectrum with several existing constellations which currently operate in mutually-exclusive frequency spectra. This is possible with a minimum of complexity and no impact to the existing constellation. Provision of a schedule of frequency use and orbital element data for the existing satellites is required. Sharing among more constellations provides additional frequency spectrum to allocate to satellites having potential conflicts. Therefore, the simultaneous coverage

conjunction (areas where one or more satellites must be "turned off" to prevent frequency interference) of satellites of all constellations becomes smaller.

One of the embodiments of the present invention supports a novel satellite, non-voice, non-geosynchronous communication system that includes a constellation of forty-eight satellites equally deployed in four pairs of low Earth orbits. These orbits are inclined at 50 degrees to the Equator. The satellites orbit in approximately orthogonal planes. A satellite leaves the Equator in one plane on an ascending node while a satellite in the orthogonal plane leaves the Equator on a descending node. The present invention, however, is not limited to such a constellation and is equally applicable to larger or smaller constellations. It is applicable to satellites in polar, inclined, or Equatorial orbits and circular, elliptical with varying foci, or highly elliptical orbits such as the Molnya orbit. The invention is independent of the type of communication service offered. The invention may be employed whenever the radio beams of one satellite in a constellation overlap those of another satellite in the same or in a different constellation. While this invention may be used for interference protection by satellites in geosynchronous (including geostationary) orbits, it is primarily concerned with preventing radio frequency interference (RFI) by new constellations of satellites in non-geosynchronous orbits with satellites in existing constellations.

For communication systems such as the forty-eight satellite constellation mentioned above, user terminals located between 34 degrees and 54 degrees latitude, the most highly populated portion of the globe, have virtually continuous access to a satellite. A preferred method of communication provides a system for transmitting a message between two terminals on the ground through a store-and-forward network. For certain user terminals located in the upper latitudes, communication may be virtually instantaneous unless there are interfering signals from other satellites in different services which could block or cause retransmission of the message.

The present invention will allow two or more satellite systems to utilize the same band of radio frequencies for communication between ground stations and satellites. This is accomplished by timing transmissions of each satellite in one constellation on one frequency or sets of frequencies so the transmissions visible at a point on the Earth do not occur simultaneously with transmissions by a satellite in a second constellation visible at the same point on the Earth on the same frequencies.

In the following discussion, a first satellite constellation, newly launched, will be referred to as "System A" and a second, existing satellite constellation will be referred to as "System B." By spacing the System A satellites in each plane so that their radio coverage footprints on the Earth do not overlap except where the orbits cross, (usually near the polar region and in some constellations near the equatorial region), there is no interference among any of System A satellites. Newly launched System A must not interfere with existing System B. A System A satellite is required to change frequency to avoid interference with a System B satellite. The System A satellite must not use a frequency already in use by a second System A satellite which overlaps the first satellite's coverage. The System A first satellite must

operate on a frequency assigned to a System A third orbital plane satellite that also does not overlap at the time. Happily, such a choice is generally available in LEO constellations so that required frequency changes do not ripple through the constellation.

To avoid having more than one satellite "visible" to a ground relay station, radio frequencies of System A satellites are allocated so that overlapping visibility contours are not assigned the same frequency. "Visible" refers to the fact that transmissions on very high frequency (VHF) or ultra high frequency (UHF) are essentially line of sight. Timing of transmissions by a satellite residing in System A is determined with reference to calculations of the ground visibility contours (radio beam footprints) of all of the satellites in System A and in those of satellites residing in System B and others if necessary. In one embodiment, a search algorithm is used to determine the choice of time and frequency in an automated fashion and scheduled days in advance.

An ephemeris data set is constructed including orbital parameter data of all of the satellites in System A and System B. The orbital parameter data includes a continuous description of the position of the radio beam footprints with time for each satellite. It also may include the operating radio frequencies assigned for each satellite in System B.

A radio frequency use schedule is then constructed using a radio frequency use schedule algorithm in a conventional central processing unit (CPU). The algorithm is used to implement a frequency avoidance plan. The algorithm determines mutual visibility of a System A satellites and a System B satellites by a terminal on the Earth by calculating the distance between satellites based on the orbital data ephemeris. The algorithm determines which satellite in the System B is impacted by a satellite in System A. Only a satellite in System A which impacts another satellite is required to change frequency.

The radio frequency use schedule is frequently updated to correct for satellite drift and other changes in satellite constellation topology. The radio frequency use schedule is periodically communicated by a ground relay station-to-satellite uplink to each satellite in System A where it is stored on board. Each satellite is then operated in accordance with the radio frequency use schedule. Frequency changes are made to avoid interfering with other satellites in the System A or System B.

A preferred radio frequency use schedule algorithm that minimizes (or prohibits) System A satellites from causing interference to System B satellites also minimizes the system outages of System A. System A outages can be caused at times when no unused frequencies are available. Different frequencies are assigned to System A satellites in each orbit plane. Frequencies at the low end and high end of the frequency bands are interleaved to minimize the number of satellites that must change frequency for any overlapping footprint conflict. Any required frequency change is made by changing to the frequency assignment of a satellite in the System A constellation to a frequency assigned to satellites in an "orthogonal" orbit plane. If such a frequency is unavailable, then any available frequency is chosen.

The frequency assignments to each of the eight orbital planes of System A are interleaved such that every odd numbered orbit plane 1, 3, 5, 7 is assigned a frequency from a first half of the frequency

spectrum and every even numbered orbit plane 2, 4, 6 and 8 is assigned a frequency from the opposite half of the spectrum. So, for example, if the Space-to-Earth spectrum ranges from 137.000 MHz to 138.000 MHz, then the odd numbered orbital planes are assigned a frequency in the band between 137.000 MHz and 137.500 MHz and the even numbered orbital planes are assigned a frequency in the band between 137.500 MHz and 138.000 MHz. Of course, the order of frequency assignment and portion of the band assigned to odd or even numbered planes may be reversed. When a frequency change is necessary for a satellite in System A, the frequency used in the paired, orthogonal plane, if available, is adopted by that satellite. If the selected frequency is not available then any available frequency may be used. The invention is not limited by the number of orbital planes comprising System B.

The methods described above may be applied to constellations described by J. G. Walker in his article *Satellite Constellations*, published in the Journal of the British Interplanetary Society, Vol. 37, 1984, pp. 559-572. Walker discloses methods for determining the size and shape of constellations of satellites able to provide continuous multiple coverage of the entire surface of the Earth needed for some applications such as navigation.

In one preferred embodiment, the method described above is used with packet transmission store and forward protocols so that infrequent interference between satellites in the System A can be tolerated due to minimal degradation caused by burst packet transmissions and packet re-transmissions.

In another, alternative embodiment, timing of the transmissions and frequency assignments is based on a satellite in System A detecting the use of a frequency by a satellite in System B and relaying that information between satellites in System A. Avoiding transmission on the same frequency by the two constellations requires all satellites in System A to detect transmissions in their field of view and change their transmitting frequency to a non-interfering frequency based on the frequency use information relayed between satellites in System A. In this embodiment, the radio frequency reuse schedule is computed on board each satellite based on the know position and frequencies of other satellites which is periodically furnished from a ground station.

An appreciation of other aims and objectives of the present invention and a more complete and comprehensive understanding of this invention may be achieved by studying the following description of preferred and alternative embodiments and by referring to the accompanying drawings.

A BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic view of a constellation of forty-eight satellites in four pairs of inclined orbits. For the sake of clarity, only two pairs of orbits are shown.

Figure 2a is a diagram showing how a satellite (A1) residing in a first constellation (System A) can transmit radio signals which, unless on a different frequency, can interfere with radio signals from another satellite (B1) residing in a second constellation (System B) when the two satellites are visible to

a ground station. Satellite A2 may transmit on the same frequency as satellite B1 because of the spatial separation of the two satellites.

Figure 2b is a diagram which depicts a satellite in System A which has a radio beam footprint overlapping the footprints of two satellites in System B which may be operating on the same frequency because of spatial separation. Simultaneously transmitted radio signals to and from the System A satellite will interfere with the signals to and from the System B satellites in the overlapping regions of the footprints.

Figure 3 is a Mercator projection of the Earth's surface showing two satellites in different constellations whose radio beam footprints do not overlap. Interference is avoided if both satellites operate simultaneously on the same radio frequency.

Figure 4 is a Mercator projection of the Earth's surface showing a plurality of satellites in two different constellations whose radio beam footprints overlap in the shaded areas, potentially causing radio frequency interference (RFI) between the two systems. For clarity, the diagram shows only radio beam footprints for satellites on or North of the Earth's Equator.

Figures 5 and 6 are charts of signal energy versus frequency for communication signals used by satellites in System A ($f_{A11}...f_{Anm}$) which occupy the same frequency bands as signals used by satellites in System B ($f_{B1}...f_{Bn}$) showing how the signal frequencies are shared.

Figure 7 is a schematic diagram of a preferred embodiment of the *Radio Frequency Sharing for Satellite Systems* depicting how orbital ephemeris data is used to create a radio frequency use schedule which is transmitted from a ground relay station via uplink to a System A satellite for use in timing the transmissions of the System A satellite which would otherwise interfere with System B satellites.

Figure 8 is a schematic view of System A satellites Ai, Aj using an alternative embodiment of *Radio Frequency Sharing for Satellite Systems*. Satellites residing in System A listen for transmissions of satellites residing in System B and change frequency to prevent interference.

Figure 9 reveals a diagram of the Earth and the orbital planes of System A satellites as seen from one pole, showing a plan for pairing frequency assignments among satellites in orthogonal orbital planes which minimizes the number of satellites in System A that must change frequency when a potential interference is caused by overlapping of System A radio-beam footprints by satellites of System B.

Figure 10 represents a terrestrial two-way wireless (radio) communications system which reuses frequencies on a cellular basis and uses LEO or MEO satellite links to connect remote receiver stations to a central or regional switching center which is in turn connected to higher power service transmitters.

A DETAILED DESCRIPTION OF PREFERRED & ALTERNATIVE EMBODIMENTS

A System of Satellites

Figure 1 is a schematic view of a constellation 10 of forty-eight satellites (A1-M) operating in four conjugate pairs of orbits 22 supported by a preferred embodiment of the present invention. For the sake of clarity, only two conjugate pairs of orbits 22 are shown. In the text that follows, the term "constellation" refers to the entire group of satellites. A complete implementation of the invention which incorporates the constellation 10 as well as equipment such as relay stations 18 or user terminals 20 on or near the surface of the Earth E is described by the term "system." In the following discussion, a first satellite constellation 10, newly launched, will be referred to as "System A" and a second, existing satellite constellation will be referred to as "System B."

The satellites 12 shown in Figure 1 operate in one preferred embodiment, in a circular orbit 14, 15 about the Earth E, which is inclined at 50 degrees to the Earth's Equator 16. In one preferred embodiment, the satellites (A1-M) are equally spaced in orthogonal pairs of orbits 22 at an altitude of 950 km. The pairs of orbits 22 are positioned so that the ascending node of one orbit 14 is displaced 180 degrees in right ascension (longitude) from the ascending node of the orthogonal, conjugate orbit 15. The ascending node of one orbit 14 must therefore occur at the same angle of right ascension as does the descending node of the orthogonal, conjugate orbit 15. Ascending nodes of adjacent orbital planes are placed at 0, 45, 90, 135, 180, 225, 270 and 315 degrees right ascension. The interplane phase angle between any two adjacent orbital planes in one embodiment is zero degrees. In another embodiment, the interplane phase angle is 7.5 degrees. The interplane phase angle is the angle between two satellites A1, AM in adjacent planes when one satellite is at the Equator 16.

The relay stations 18 are located on the ground and distributed internationally in a pattern of locations on the Earth which maximize coverage and minimize time to forward messages and data between any two user terminals. In a preferred embodiment of the System A, there are approximately ten to one hundred "distributed" relay stations 18. The relay stations 18 are capable of communicating with the satellites A1-M in orbit via uplinks and downlinks. The relay stations 18 may be connected to terrestrial based networks such as public telephone networks.

User terminals 20 are randomly distributed over the Earth's surface and are also capable of communicating with the satellites A1-M. The user terminals 20 may be fixed, mobile or portable. They may be located on land, at sea or in the air.

The parameters given above are for a preferred embodiment of a System A of communication satellites A1-M used in the invention. It will be appreciated by those skilled in the art that the methods and apparatus described are equally applicable to larger or smaller constellations. It is applicable to satellites in polar, inclined, or Equatorial orbits and circular, elliptical with varying foci or highly elliptical orbits such as the Molnya orbit. The invention is independent of the type of communication service offered. Use

of the invention is desirable whenever the radio beams of one satellite in a System A overlap those of another satellite in the same or in a different System B. While this invention may be used for interference protection by satellites in geosynchronous (including geostationary) orbits, it is primarily concerned with preventing radio frequency interference (RFI) by new constellations of satellites $A_{1\text{-}M}$ in non-geosynchronous orbits with satellites $B_{1\text{-}N}$ in existing systems. For example, the altitude of the satellites may be other than 950 km so long as it is greater than 100 km and substantially less than geostationary altitude. The altitudes of satellites in differing orbits may be different. The inclination of the orbit planes 14, 15 may vary from 0 degrees to 180 degrees and the inclination of a plane may differ from other planes. The interplane phase angle between satellites in adjacent orbits may vary between 0 degrees and 360 degrees and may be different between adjacent orbit planes. Further, the number of satellites per orbital plane 14, 15 may be any positive integer, and the total number of satellites is given by the number of orbital planes 14, 15 multiplied by the number of satellites per plane. A constellation 10 may be created in which the number of orbital planes (N) is an even, positive integer and the ascending nodes of the planes are positioned at right ascension angles of 0, 180, 360/N, 360/N+180,...,k*360/N, k*360/N+180,...,(N/2-1)*360/N, (N/2-1)*360/N+180 degrees.

Telecommunication Frequencies and Spectrum

The present invention has been designed from the outset to make efficient use of the scarce spectrum that is currently available. As an example of this scarcity, Table One below summarizes the total spectrum available in the U.S. for a typical non-voice non-geosynchronous (NVNG) type of service, resulting from the allocations made at WARC-92 and in the Federal Communication Commission's Order allocating spectrum for the NVNG Mobile Satellite Systems.

Table One - Mobile Satellite System Frequency Allocations Below 1 GHz

Earth-to-Space	Space-to-Earth
148.000 to 150.050 MHz	137.000 to 138.000 MHz
399.900 to 400.050 MHz	400.150 to 401.000 MHz

The table shows a total of 2.2 MHz available for the Earth-to-space links (uplink) and 1.85 MHz for the Space-to-Earth links (downlink). However, parts of this available spectrum are only allocated on a secondary basis to the MSS service, and even the primary MSS allocations are allocated on a co-primary basis to other services, such as Fixed, Mobile, Meteorological-Satellite, Space Operation, Space Research and Meteorological Aids. The ability of the system to effectively and efficiently share the spectrum in this type of environment is therefore of paramount importance.

Radio Frequency Interference Between Satellite Systems

Figure 2a is a diagram showing how a satellite A1 residing in a first constellation (System A) can transmit radio signals which unless on a different frequency, can interfere with radio signals from another satellite B1 residing in a second constellation (System B). Satellite B1 is flying in orbit 12. Satellites A1 and A2 are positioned in different orbits from the one satellite B1 is flying in. In its current position, satellite A1 is visible to the same terrestrial relay station 18 or user terminal 20 as is visible to satellite B1. "Visible" refers to the fact that transmissions at very high frequency (VHF) or ultra high frequency (UHF) and above are essentially line of sight. The two satellites A1, B1 are visible to the ground relay station 18 or user terminal 20 nearest satellite B1 in this figure. In its current position, satellite A2 is not visible to the same terrestrial relay station 18 or user terminal 20 as is either satellite A1 or satellite B1. Therefore, at their present positions, satellite A1 may not simultaneously transmit signals on the same frequency f2 as satellite B since the signal from satellite A1 will interfere with that of satellite B1 at the terrestrial relay station 18 or user terminal 20 nearest satellite B1. Satellite A1 may transmit on the same frequency f1 as satellite A2 because the spatial separation of the two satellites prevents interference between the two signals at the terrestrial station 18 or user terminal 20. Satellite A2 may also transmit simultaneously with satellite B1 on frequency f2 because the spatial separation of the two satellites A2, B1 prevents interference between the two signals at the terrestrial station 18 nearest satellite B1.

Figure 2b is a diagram which depicts a satellite in System A which has a radio beam footprint 30 overlapping the footprint 35 of each of two System B satellites B1, B2. Satellites B1 and B2 may be operating on the same frequency because spatial separation permits them to do so. Radio beams 36 to and from System A satellite A1 in the overlapping regions 34 of the footprints 30, 35 will interfere with the signals to and from the System B satellites B1, B2 if simultaneously transmitted. Satellite A1 must therefore operate at a frequency different from that used by satellites B1 or B2 to avoid interfering with any System B users within the overlapping regions 34.

Figure 3 is a Mercator projection 37a of the Earth's surface showing radio beam footprints 30, 35 of two satellites A1, B1 in different Systems A, B which at their present positions do not overlap and hence there is no interference if both satellites operate simultaneously on the same radio frequency f_1. However, as the satellites move in their orbits, there may come a time when the radio beam footprints 30, 35 overlap and one satellite must operate on a different frequency in order to prevent interference between simultaneous signals to or from the two satellites A1, B1 as shown in Figure 2b.

Figure 4 is a Mercator projection 37b of the Earth's surface showing a plurality of satellites in two different Systems A, B whose radio beam footprints 30, 35 overlap in the shaded areas 34. For clarity, the projection has been limited to satellites having footprints 30, 35 between latitudes 38 of sixty degrees North and thirty degrees South. There is potential radio frequency interference (RFI) in the overlapping (shaded) areas 34, if simultaneous transmissions on the same frequencies (fi) are made by satellites whose footprints 30, 35 overlap.

For certain user terminals 20 located in the these upper latitudes, communication may be virtually instantaneous unless there are interfering signals from other satellites (B1-N) which could block or cause retransmission of the message. Therefore, elimination of this interference will greatly enhance the efficiency of both systems, thereby greatly improving the services for users.

Figure 5 is a chart of signal energy versus frequency for communication signals usable by satellites in System A ($f_{A11}...f_{A1n}$) which occupy the first frequency band used by satellites in System B (f_{B1}). Figure 6 is a chart of signal energy versus frequency for communication signals used by the satellites in System A ($fA_{m1}...f_{Amn}$) which occupy the mth band used by satellites in System B (f_{Bmn}). Satellites in System B operate using frequency bands $f_{B1}...f_{Bm}$. Satellites in System A operate using frequency bands $f_{A11}...f_{Anm}$. These charts depict graphically how the limited signal frequencies available are shared by satellites in System A and System B.

To avoid having more than one satellite "visible" to a ground relay station 18, radio frequencies of System A satellites are allocated so that overlapping visibility contours are not assigned the same frequency. Timing of transmissions by a satellite residing in System A is determined with reference to calculations of the ground visibility contours (radio beam footprints) of all of the satellites in System A and in those of satellites residing in System B and others if necessary.

Radio Frequency Sharing Methods for Satellite Systems

The present invention will allow two or more satellite Systems A, B to utilize the same band of radio frequencies for communication between ground stations 18, 20 and satellites A1-M, B1-N. The invention prevents or minimizes interference between the satellite radio signals at terrestrial terminals 18, 20 which are in the overlap area 34 of radio beams 32, 36 of two satellites of different systems A, B or of the same System A directly served by the invention. This is accomplished when the available frequencies are shared and when the satellite footprints 30, 35 overlap, by timing transmissions of each System A satellite A1-M on a frequency fi or sets of frequencies selected from $f_{A11}...f_{Anm}$ so the transmissions do not occur simultaneously with transmissions on identical frequencies by a System B satellite B1-N within any overlapping regions 34.

Figure 7 is a schematic diagram of a preferred embodiment of the *Radio Frequency Sharing Methods for Satellite Systems*. It depicts how orbital ephemeris data 46 is used to create a radio frequency use schedule 49 which is transmitted from a ground relay station 18 via uplink to a satellite for use in timing transmissions of the System A satellite Ai which would otherwise interfere with one or more System B satellites.

Orbital data and radio frequency assignments for satellites A1-M in System A and satellites B1-N in other Systems B, are collected in the orbital data ephemeris 46. The position of satellite footprints 30, 35 and the distances between them are computed and continually updated. This data is used by a radio frequency use schedule algorithm 48 to produce a frequency use schedule 49. Storage of the ephemeris

data 46 and computation of the radio frequency use schedule 49 is accomplished by conventional computing means. The radio frequency use schedule 49 is transmitted periodically as necessary to each satellite Ai residing in System A by an uplink 50 from a ground relay station 18.

Figure 8 is a schematic view of System A satellites using an alternative embodiment of *Radio Frequency Sharing Methods for Satellite Systems*. Satellites residing in System A listen for transmissions of satellites residing in System B to determine when to change transmission frequency. The frequency intercepted by satellite Ai is sent to all satellites in the system. In this embodiment, the orbital parameter ephemeris 46 is maintained on board each satellite A1-M and the radio frequency use schedule 49 is computed on board the satellites A1-M by use of the radio frequency use schedule algorithm 48. Of course, the ephemeris 46 and algorithm 48 may be also maintained and computed on the Earth in the event cost and power use are to be conserved. In that event, the satellite which intercepts the frequency being used by the System B satellite B1 transmits the information to the nearest ground relay station 18 for processing.

Frequency Assignments and Pairing

A frequency assignment plan for System A satellites A1-M is dependent on the topology of System A. For purposes of illustrating an embodiment of the invention as applied to one type of constellation, consider a newly launched, 48-satellite system, System A, having eight inclined orbital planes. The planes are numbered 1 through 8 for convenience. Each satellite A1-M in the same plane is assigned the same communication frequency (eight frequencies used in this case). By spacing the satellites A1-M in each plane so that their radio coverage footprints 30 on the Earth E do not overlap except where the orbits 14, 15 cross, there is no interference among any of System A satellites A1-M. For simplification, assume that System B, which will share radio frequencies with System A, is an existing constellation having no more than four communication frequencies which are the same as those used by System A. Newly launched System A must not interfere with existing System B. When a System A satellite A1-M is required to change frequency to avoid interference with a System B satellite B1-M, the System A satellite A1-M must not use a frequency already in use by a second System A satellite A1-M which overlaps the first satellite's coverage. The first System A satellite A1-M must operate on a frequency assigned to a third System A orbital plane that also does not overlap at the time. Happily, such a choice is generally available in LEO constellations so that required frequency changes do not ripple through the constellation.

The schedule of these events, as described above, can be stored on board each satellite. Frequency changes can be executed by on-board command at the appropriate time or commanded in real time by a ground control station, using cross-links between satellites A1-M if necessary.

For the system of 48 satellites A1-M in inclined, orthogonal, conjugate orbits 14, 15 described above, a plan for pairing of assigned frequencies f1-n is shown in Figure 9. This figure reveals a diagram of the Earth E and the orbital planes 14, 15 of System A satellites shown in one preferred embodiment as polar orbits. The reader will appreciate that a polar orbit is a special case of inclined orbit wherein the

angle of inclination with the Equator EQ is ninety degrees. It shows a plan for pairing frequency assignments among satellites A1-M in orthogonal orbital planes 14, 15. The pairing minimizes the number of satellites A1-M that must change frequency f_{1-m} when a potential interference is caused by overlapping of a System A radio-beam footprint 30 by a footprint 35 of System B satellites B1-N. For the eight planes depicted and eight available frequencies f1-8, the paired frequency is assigned to satellites in orthogonal, conjugate planes 14, 15. Thus, for a given time period t, satellites in plane 1 are assigned to frequency f1. Satellites in plane 2 are assigned to frequency f6, satellites in plane 3 are assigned to frequency f3, and so forth as shown in Figure 9. At such time as a satellite must change frequency to avoid a conflict with another with overlapping coverage, the frequency is changed to that of the frequency assigned to satellites in the orthogonal orbit plane, if available. As a result, a satellite in plane 1 would shift to f5, the frequency assigned to plane 5; a satellite in plane 2 would shift to f2, the frequency assigned to plane 5; a satellite in plane 3 would shift to f7; a satellite in plane 4 would shift to f4; a satellite in plane 5 would shift to f1; a satellite in plane 6 would shift to f2; a satellite in plane 7 would shift to f3; and a satellite in plane 8 would shift to f8.

By switching to frequencies from orthogonal planes 15, conflicts are avoided, except near the polar region, for the constellation depicted in Figure 9. Because many satellites can service the polar regions, little or no coverage is lost even if one satellite A1-M must be switched off to avoid interference.

In the case of some conflicting satellite systems, such pairing minimizes the probability of a System B overlapping footprint 35 requiring a change in more than two frequencies. As has been noted previously, the radio frequency use algorithm implements such pairings and choices for frequency changes. For a time when an interference is predicted, the algorithm will require a frequency change from that first assigned to that of an orthogonal plane 15. If a selected frequency is unavailable then any available frequency is selected. At least one frequency is always available.

The frequency assignments to each of the eight orbital planes of System A are interleaved such that every odd numbered orbit plane 1, 3, 5, 7 is assigned a frequency from a first half of the frequency spectrum and every even numbered orbit plane 2, 4, 6 and 8 is assigned a frequency from a second half of the spectrum. So, for example, if the Space-to-Earth spectrum ranges from 137.000 MHz to 138.000 MHz, then the odd numbered orbital planes 14, 15 are assigned a frequency in the band between 137.000 MHz and 137.500 MHz and the even numbered orbital planes 14, 15 are assigned a frequency in the band between 137.500 MHz and 138.000 MHz.

When a frequency change is necessary for a satellite A1-M in System A, the frequency used in the paired, orthogonal plane 15, if available, is adopted by that satellite. If the selected frequency is not available then any available frequency may be used. Of course, the order of frequency assignment, from lowest to highest, and the portion of the band assigned to odd or even numbered planes 14, 15 may be reversed or randomized.

Much of the time, there are usually two System A orbit planes, each assigned a different frequency, in which satellite footprints 30 do not present radio interference with footprints 30 in the other planes. These two planes are always adjacent planes. Therefore, interleaving the frequency assignments in each plane such that every other frequency is in an opposite half of the available spectrum, increases the probability that a frequency will be available to which a System A satellite in conflict can switch.

In the System B constellation postulated, only half of the available spectrum is required. Therefore only one-half of the System A satellites $A_{1\text{-}M}$ are possibly impacted by frequency conflicts at any one time. However, the invention is not limited by the number of orbital planes comprising System B.

Uniform Global Coverage Constellations

The methods described above may be applied to constellations described by J. G. Walker in his article *Satellite Constellations*, published in the Journal of the British Interplanetary Society, Vol. 37, 1984, pp. 559-572. Walker discloses methods for determining the size and shape of constellations of satellites able to provide continuous multiple coverage of the entire surface of the Earth needed for some applications such as navigation. These constellations require precise phasing of satellites in each orbit plane and between orbit planes. This results in a regular pattern of overlapping 34 and non-overlapping footprints 30, 35, which can be exploited for frequency selection. The periods of non-overlapping footprints minimizes the number of frequency changes required for each satellite.

A typical Walker constellation for System A might comprise 48 satellites in eight orbit planes, inclined at 50 degrees, the satellites being spaced 60 degrees apart along the plane of orbit. The satellites are phased at 7.5 degrees (a satellite in one plane has advanced 7.5 degrees from the equator EQ when a satellite in an adjacent plane is just crossing the equator EQ). At 950 km altitude, there is no interference between satellites in the same plane since their radio horizons, and hence their footprints do not overlap.

As each System A satellite travels in its orbit plane, its footprint 30 overlaps with four of its neighboring satellites in adjacent planes on either side. Thus frequencies assigned to these adjacent planes can never be used by the affected satellite. Similar patterns exist for all satellites in the constellation.

As in the case of the constellation described above, in a System A Walker constellation there are usually two orbit planes in which satellites do not present radio interference with satellites in the other planes. As a result, conflicts between a System A and a System B satellite during this time can be obviated by switching the System A satellite to one of the two non-conflicting frequencies.

For a short period of time, twice each orbital revolution, a System A satellite is in contact with satellites in all System A orbital planes. During this time, if there is a conflict between a System A satellite and a System B satellite, the conflict cannot be resolved without changing the frequency of two System A satellites unless an additional frequency outside of System A assignments is available. If a System C frequency is available that is not used by System B, it can be used by an impacted System A satellite. The

inclusion of a third (System C) constellation's spectrum in the spectrum available to System A can facilitate frequency sharing and increase spectrum reuse.

The above examples of frequency sharing plans do not exhaust all of the possibilities but serve to illustrate the process of selecting and assigning communication frequencies which will prevent or at least minimize frequency conflicts between satellites in newly launched constellations and existing ones, without impacting the existing constellations.

A Method for Facilitating the Deployment of Nationwide Two-Way Paging Networks

Figure 10 represents a terrestrial two-way wireless (radio) communications system 70 which reuses frequencies on a cellular basis and uses LEO or MEO satellite links 72, 78 to connect remote receiver stations RT to a central or regional switching center 76 which is in turn connected to higher power service transmitters Tx. The system uses fixed location service transmitters Tx to transmit toward lower power mobile or portable subscriber units 74. Within the service area of a transmitter Tx, the subscriber units 74 are able to receive signals from the higher powered fixed location service transmitter Tx but they do not have enough power to transmit back to the fixed location service transmitter Tx. Satellite transceivers RT are deployed around the fixed location service transmitters to pick up the low power signals from the subscriber units 74 and relay the signal to a central or regional switching center 76. The central or regional switching center 76 is then able to complete a two way path for communications (for example, through the public switched telephone system) and is able to determine the general location of the subscriber unit 74 for the purpose of optimizing network traffic and service quality. The switching center 76 communicates to the satellite Ai through link 72 via the switching center antenna 80. The transceivers RT are coupled to the switching center 76 through links 78 to a satellite Ai and from the satellite Ai through link 72.

INDUSTRIAL APPLICABILITY

The *Radio Frequency Sharing Methods for Satellite System* described above will provide frequency sharing among satellites of a new constellation and satellites that are already in orbit. The present invention will offer a wide range of communications services while enhancing the use of currently available spectrum.

CONCLUSION

Although the present invention has been described in detail with reference to a particular preferred embodiment and alternative embodiment, persons possessing ordinary skill in the art to which this invention pertains will appreciate that various modifications and enhancements may be made without departing from the spirit and scope of the claims that follow. The various orbital parameters, altitudes and constellation populations, locations of the user terminals 20 and relay stations 18 and frequency avoidance plans implemented by the frequency use schedule algorithm 48 that have been disclosed above are intended to educate the reader about preferred embodiments, and are not intended to constrain the limits of the invention or the scope of the Claims. The List of Reference Characters which follows is intended to provide the reader with a convenient means of identifying elements of the invention in the Specification and Drawings. This list is not intended to delineate or narrow the scope of the Claims.

LIST OF REFERENCE CHARACTERS

Figures 1 through 9

10	Constellation or System "A" of satellites
12	Orbit of constellation or System "B" satellites
14	Orbital plane of System "A" satellites
15	Orthogonal orbital plane of System "A" satellites
16	Equator
18	Ground relay station
20	Distributed user terminals
22	Orthogonal pairs of satellite orbits
30	Footprint of radio beam from A constellation satellite
32	Radio beam from B constellation satellite
34	Overlap of footprints of radio beams from A and B System satellites
35	Footprint of radio beam from System B satellite
36	Radio beam from System A satellite
37a	Mercator projection of the Earth and footprints of one System A satellite and one System B satellite
37b	Mercator projection of the Earth and footprints of a plurality of System A satellites overlapping a plurality of footprints of System B satellites
38	Latitude Scale of Mercator projection of the globe
39	Longitude scale of Mercator projection of the globe
40	Radio frequency spectrum used by a System B first satellite

42	Radio frequency spectrum used by a System B Nth satellite
46	Orbital ephemeris electronic data table
48	Radio frequency use schedule algorithm computation
49	Computed frequency-use schedule electronic data
50	Ground relay station-to-satellite uplink
60	Intersatellite radio link
70	Terrestrial two-way wireless system
72	LEO/MEO satellite-to-switching center link
74	Remote receiver
76	Central or regional switching center
78	Remote transceiver-to-satellite link
80	Switching center antenna
A1	First satellite in System A constellation
A2	Second satellite in System A constellation
AM	Last satellite in System A constellation
Ai	ith satellite in System A constellation
Aj	jth satellite in System A constellation
f_{Akl}	Radio frequencies used by System A satellites: k=1...n; l=1...m
f_{Bp}	Radio frequencies used by System B satellites: p=1...n
B1	First satellite in System B constellation
B2	Second satellite in System B constellation
Bi	ith satellite in System B constellation
BN	Last satellite in System B constellation
Ci	ith satellite in a third or System C constellation
E	Earth
EQ	Equator
fi	ith frequency used by satellites
t	Time period for frequency use
m	Number of frequency bands used by System A
n	Number of frequency bands used by System B
RT	Transceiver station
Tx	Fixed-location service transmitter

CLAIMS

1. A method of radio frequency sharing between satellites (A1-M) in a first system (A) and satellites (B1-N) in a second system (B), the method comprising the steps of:

assigning an initial communication frequency to all said satellites (A1-M), said initial communication frequency being identical for all satellites (A1-M) residing in a same orbital plane (14, 15);

changing said initial communication frequency (f_{Ai}) assigned to one of said satellites (Ai) in said first system (A), to a frequency (f_{Aj}) assigned to one or more other satellites (Aj) in said first system (A), when a radio beam footprint (30) of said satellite (Ai) overlaps a radio beam footprint (35) of one of said satellites (B1-N) residing in said second system (B) and said radio frequencies being in use by respective said satellites (A1-M, B1-N) will interfere; said frequency (f_{Aj}) being one which does not interfere with any other satellite (A1-M) in said first System (A) or a satellite (B1-N) in said second system (B); and

effecting timing of said changing said initial communication frequency (f_{Ai}) by using a radio frequency use schedule (49) computed in advance from orbital parameter ephemeris data (46) for said satellites (A1-M) in said first system (A) and satellites (B1-N) in said second system (B).

2. The method as claimed in Claim 1, said satellites of said first system (A) being in communication with Earth (E) through a plurality of ground relay stations (18) and user terminals (20), said first system (A) having a plurality of orbit planes (14, 15) containing said satellites (A1-M), and said initial communication frequency being identical for all satellites (A1-M) residing in a same orbital plane (14, 15).

3. The method as claimed in Claim 2, in which the orbit planes are assigned odd and even numbers taken successively with changing longitude and in which the step of assigning an initial communication frequency to all said satellites (A1-M) in each one of said plurality of orbit planes (14, 15) of said first system (A) further includes the step of:

assigning said initial communication frequency (f_{Ai}) by interleaving the frequency assignments to each of the orbital planes (14, 15) of said first system (A) such that every odd numbered orbit plane is assigned a frequency from a first half of an authorized frequency spectrum and every even numbered orbit plane is assigned a frequency from a second half of the spectrum.

4. The method as claimed in Claim 3, in which the step of assigning said initial communication frequency (f_{Ai}) by interleaving the frequency assignments to each of the orbital planes (14, 15) of said first system (A) includes the step of:

assigning said frequency from said first half of an authorized frequency spectrum in an order proceeding from a lower frequency (f1) to a higher frequency (f7) and assigning said frequency from said second half of an authorized frequency spectrum in an order proceeding from a higher frequency (f6) to a lower frequency (f2).

5. The method as claimed in Claim 3, in which the step of changing said initial communication frequency (f_{Ai}) assigned to one of said satellites (Ai) residing in a first one of said orbital planes (14) of said first System (A), includes the step of changing said initial communication frequency (f_{Ai}) to a frequency (f_{Aj}) initially assigned to satellites (Aj) residing in an orthogonal orbit plane (15) of said first System (A).

6. The method as claimed in Claim 3, in which the step of changing said initial communication frequency (f_{Ai}) assigned to one of said satellites (Ai) residing in a first one of said orbital planes (14) of said first System (A), includes the step of changing said initial communication frequency (f_{Ai}) to a frequency (fci) initially assigned to satellites (Ci) residing in a third system (C) in which said satellites (Ci) do not present radio interference with satellites (A1-M) in said first system (A).

7. The method as claimed in any preceding Claim, further including the step of:

using packet transmission store and forward protocols for said communication between said satellites of said first system (A), said plurality of ground relay stations (18) and said user terminals (20) to reduce infrequent interference between satellites in said first System (A) and said second system (B) caused by burst packet transmissions and packet re-transmissions.

8. The method as claimed in any preceding Claim, in which the step of effecting timing of said changing said initial communication frequency (f_{Ai}) by using a radio frequency use schedule (49) computed in advance from orbital ephemeris data (46) for said satellites (A1-M) in said first system (A) and satellites (B1-N) in said second system (B) includes the steps of:

listening for transmissions of satellites (B1-N) residing in said second system (B) with satellites (A1-M) residing in said first system (A); intercepting said transmissions and determining the frequency (f_{Bp}) of said transmissions and time to change said initial communication frequency (f_{Ai});

transmitting said frequency (f_{Bp}) and said time determined by said satellites (A1-M) to all said satellites (A1-M) in said first System (A) and to at least one of said plurality of ground relay stations (18); and

maintaining said frequency (f_{Bp}) and time as data in said orbital parameter ephemeris (46) and computing on board each of said satellites (A1-M) said radio frequency use schedule (49) by use of a radio frequency use schedule algorithm (48).

9. The method as claimed in Claim 8, in which the step of maintaining said frequency (f_{Bp}) and time as data in said orbital parameter ephemeris (46) and computing said radio frequency use schedule (49) is accomplished on board each said satellite (A1-M).

10. The method as claimed in Claim 8, in which the step of maintaining said frequency (f_{B_p}) and time as data in said orbital parameter ephemeris (46) and computing said radio frequency use schedule (49) is accomplished on the Earth (E) and furnished to each said satellite (A1-M) from one of said plurality of ground relay stations (18).

11. A method of radio frequency sharing between satellites in a first system (A) and satellites (B1-N) in a second system (B), said first system (A) having a plurality of inclined orbit planes (14, 15) containing said satellites (A1-M), said satellites (A1-M) of said first system (A) being in communication with Earth (E) through a plurality of ground relay stations (18) and user terminals (20), the method comprising the steps of:

generating an ephemeris of orbital parameters (46);

said ephemeris of orbital parameters (46) including orbital parameter data describing operating frequencies and paths over the Earth (E) of each one of a plurality of satellites (A1-M) residing in said first system (A) and each one of a plurality of satellites (B1-N) residing in said second system (B);

each one of said plurality of satellites (A1-M) residing in said first system (A) having a radio beam footprint (30), and each one of said plurality of satellites (B1-N) residing in a second constellation (B) having a radio beam footprint (35);

computing a radio frequency use schedule (49) with a radio frequency use schedule algorithm (48);

said radio frequency use schedule algorithm (48) having as an input, said orbital parameter data (47) from said ephemeris of orbital parameters (46);

said radio frequency use schedule (49) providing an available time for transmission (t) at each radio frequency (f1-n) for each one of said plurality of satellites (A1-M) residing in said first system (A), depending upon a time of overlap of said footprint (30) of each one of said satellites (A1-M) and said footprint (35) of one of said satellites (B1-N) residing in said second system (B), and when said radio frequencies being in use by respective said satellites (A1-M, B1-N) will interfere;

transmitting electronically said radio frequency use schedule (49) to each of said satellites (A1-M) in said first system (A) through at least one of said plurality of ground relay stations (18);

storing said radio frequency use schedule (49) on board each one of said satellites (A1-M) in said first system (A); and

operating each one of said satellites (A1-M) residing in said first system (A) in accordance with said available time for transmission (t) at each radio frequency (f1-n) to obviate radio frequency interference (RFI) between each one of said satellites (A1-M) residing in said first system (A) and each one of said satellites (B1-N) residing in said second system (B).

12. The method as claimed in Claim 11, further including the step of:

using packet transmission store and forward protocols for said communication between said satellites of said first system (A) and said plurality of ground relay stations (18) and user terminals (20) to reduce infrequent interference between satellites in said first system and said second system caused by burst packet transmissions and packet re-transmissions.

13. The method as claimed in Claim 11 or 12, further including the steps of:

assigning an initial communication frequency (f_{Ai}) to all said satellites (A1-M) in each one of said plurality of orbit planes (14, 15) of said first system (A); said initial communication frequency being identical for all satellites (A1-M) residing in a same orbital plane (14, 15).

14. The method as claimed in Claim 13, further including the steps of:

changing said initial communication frequency (f_{Ai}) assigned to one of said satellites (Ai) residing in a first one of said orbital planes (14) of said first system (A), to a frequency (f_{Aj}) assigned to satellites (Aj) residing in a second one of said orbital planes (15) of said first system (A), when a radio beam footprint (30) of said satellite (Ai) overlaps a radio beam footprint (35) of one of said satellites (Bi) residing in said second system (B) and said radio frequencies (f_{Ai}, f_{Bi}) being in use by respective said satellites (Ai, Bi) will interfere; said frequency (f_{Aj}) being one which does not interfere with any other satellite (A1-M) in said first system (A) or a said satellite (B1-N) in said second system (B); and

effecting timing of said changing said initial communication frequency (f_{Ai}) by using said radio frequency use schedule (49) computed in advance from said orbital parameter ephemeris data (46) for said satellites (A1-M) in said first system (A) and said satellites (B1-N) in said second system (B).

15. The method as claimed in Claim 14, in which the orbit planes are assigned odd and even numbers taken successively with changing longitude and in which the step of assigning an initial communication frequency to all said satellites (A1-M) in each one of said plurality of orbit planes (14, 15) of said first system (A) further includes the step of:

assigning said initial communication frequency (f_{Ai}) by interleaving the frequency assignments to each of the orbital planes (14, 15) of said first system (A) such that every odd numbered orbit plane (1, 3, 5, 7) is assigned a frequency (f1, f3, f5, f7) from a first half of an authorized frequency spectrum and every even numbered orbit plane (2, 4, 6, 8) is assigned a frequency (f2, f4, f6, f8) from a second half of said authorized spectrum.

16. The method as claimed in Claim 14, further including the step of changing said initial communication frequency (f_{Ai}) assigned to one of said satellites (Ai) residing in a first one of said orbital planes (14) of said first system (A) to a frequency (f_{Aj}) initially assigned to satellites (Aj) residing in an orthogonal orbit plane (15) of said first system (A).

17. The method as claimed in Claim 14, in which the step of changing said initial communication frequency (f_{Ai}) assigned to one of said satellites (Ai) residing in a first one of said orbital planes (14) of said first System (A), includes the step of changing said initial communication frequency (f_{Ai}) to a frequency (fci) assigned to satellites (Ci) residing in a third system (C) in which said satellites (Ci) do not present radio interference with satellites (A1-M) in said first system (A).

18. A method of radio frequency sharing between satellites in a first system (A) and satellites in a second system (B), said first system (A) having a plurality of orbit planes (14, 15) containing said satellites (A1-M), the method comprising the steps of:

detecting the use of a frequency by a satellite (B1-N) in said second system (B) with an affected satellite (Ai) in said first system (A);

relaying information of said frequency use to all satellites in said first system (A);

computing a radio frequency reuse schedule (49) based on said frequency use information relayed between satellites in said first system (A); and

changing the transmitting frequency of said affected satellite (Ai) in said first system (A) to a non-interfering frequency based on said frequency use schedule (49).

19. The method as claimed in Claim 18, in which the step of computing said radio frequency reuse schedule (49) is accomplished on board each said satellite (A1-M).

20. The method as claimed in Claim 18, in which said frequency use information is also relayed to at least one of a plurality of ground relay terminals (18) and the step of computing said radio frequency reuse schedule (49) is accomplished on the Earth (E) and furnished to each of said satellites (A1-M) from at least one of said plurality of ground relay stations (18).

21. A two-way communications system for a portable, low-power mobile or fixed subscriber unit (74) comprising:

a central switching center (76);

said central switching center (76) connected to a public switched telephone network (PSTN);

a plurality of fixed location service transmitters (Tx); each one of said plurality of fixed location service transmitters (Tx) being coupled to said central switching center (76), each one of said fixed location service transmitters (Tx) providing communications transmissions to said subscriber unit (74) within an omnidirectional service area;

a plurality of remote receiver stations (RT), each one of said remote transceiver stations (RT) coupled to said central switching center (76); and

said remote transceiver stations (RT) being deployed in said service areas around said fixed location service transmitters (Tx) and capable of receiving low power signals from said subscriber unit (74);

said low-power signals from said subscriber unit (74) being received by said remote transceiver (RT) and relayed to said public switched telephone system (PSTN) through said central switching center (76);

communications from said public switched telephone network system (PSTN) being relayed to said subscriber unit (74) directly from said service transmitter (Tx), whereby a two-way communication path is completed, and a general location of said subscriber unit (74) is determined for the purpose of optimizing network traffic and service quality.

22. The two-way communications system as claimed in Claim 24, in which the coupling between said remote transceiver stations (76) and said central switching center (76) is provided by satellite radio links (78, 72).

23. A method of radio frequency sharing between satellites in a first System (A) and satellites in a second System (B), said satellites of said first system being in communication with Earth through a plurality of ground relay stations (18) and user terminals (20), the method comprising the steps of:

generating an ephemeris of orbital parameters (46);

said ephemeris of orbital parameters (46) including orbital parameter data describing operating frequencies and paths over the Earth (E) of each one of a plurality of satellites ($A_{1\text{-}M}$) residing in said first system (A) and each one of a plurality of satellites ($B_{1\text{-}N}$) residing in said second system (B);

each one of said plurality of satellites ($A_{1\text{-}M}$) residing in said first system (A) having a radio beam footprint (30), and each one of said plurality of satellites ($B_{1\text{-}N}$) residing in a second constellation (B) having a radio beam footprint (35);

computing a radio frequency use schedule (49) with a radio frequency use schedule algorithm (48);

said radio frequency use schedule algorithm (48) having as an input, said orbital parameter data (47) from said ephemeris of orbital parameters (46);

said radio frequency use schedule (49) providing an available time for transmission (t) at each radio frequency (f1-n) for each one of said plurality of satellites ($A_{1\text{-}M}$) residing in said first System (A), depending upon a time of overlap of said footprint (30) of each one of said satellites ($A_{1\text{-}M}$) and said footprint (35) of one of said satellites ($B_{1\text{-}N}$) residing in said second System (B), and when said radio frequencies being in use by respective said satellites ($A_{1\text{-}M}$, $B_{1\text{-}N}$) will interfere;

transmitting electronically said radio frequency use schedule (49) to each of said satellites ($A_{1\text{-}M}$) in said first system (A) through at least one of said plurality of ground relay stations (18);

storing said radio-frequency use schedule (49) on board each one of said satellites ($A_{1\text{-}M}$) in said first system (A); and

operating each one of said satellites (A_{1-M}) residing in said first system (A) in accordance with said available time for transmission (t) at each radio frequency (f_{1-n}) to obviate radio-frequency interference (RFI) between each one of said satellites (A_{1-M}) residing in said first system (A) and each one of said satellites (B_{1-N}) residing in said second system (B).

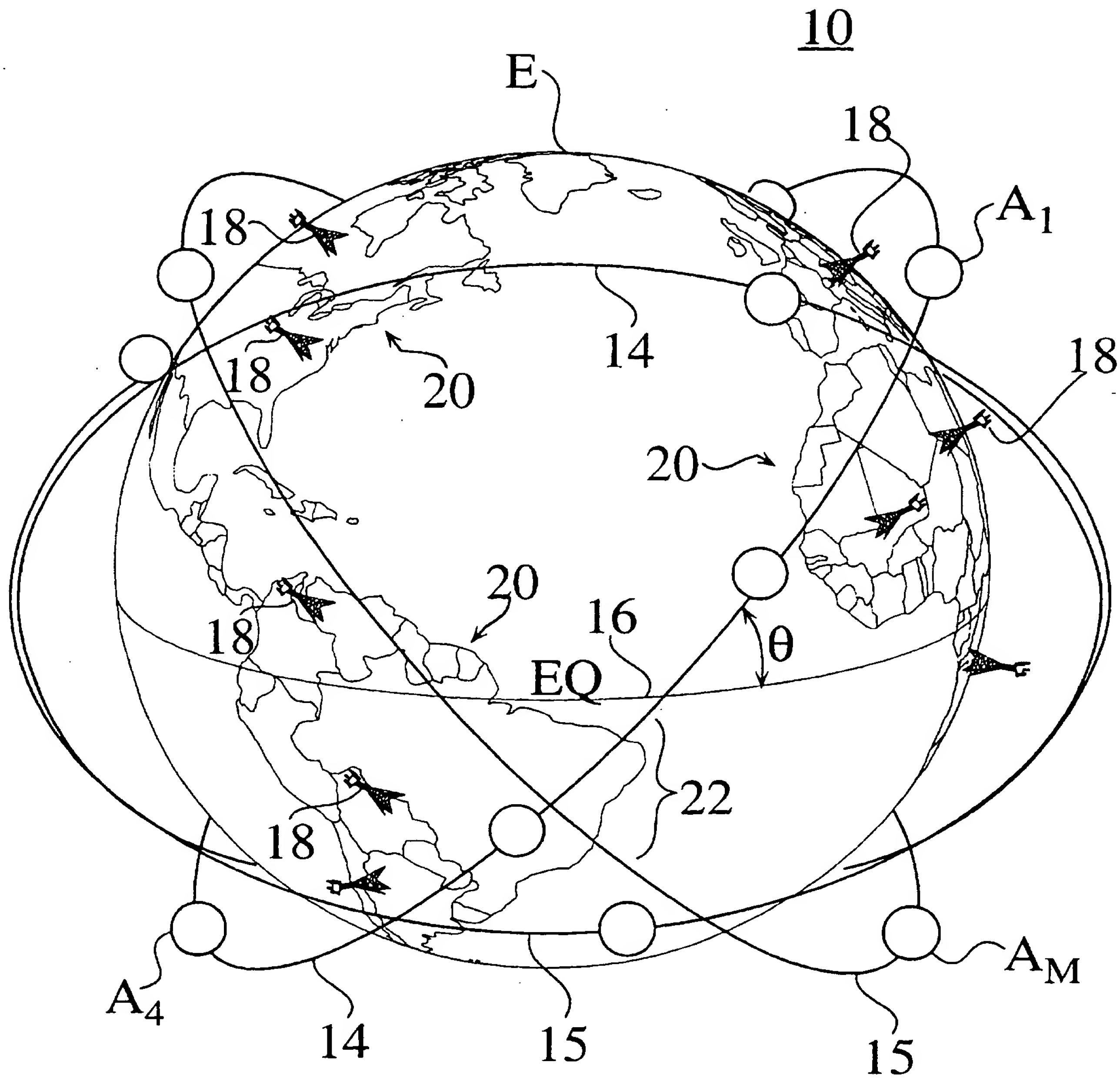


Fig. 1

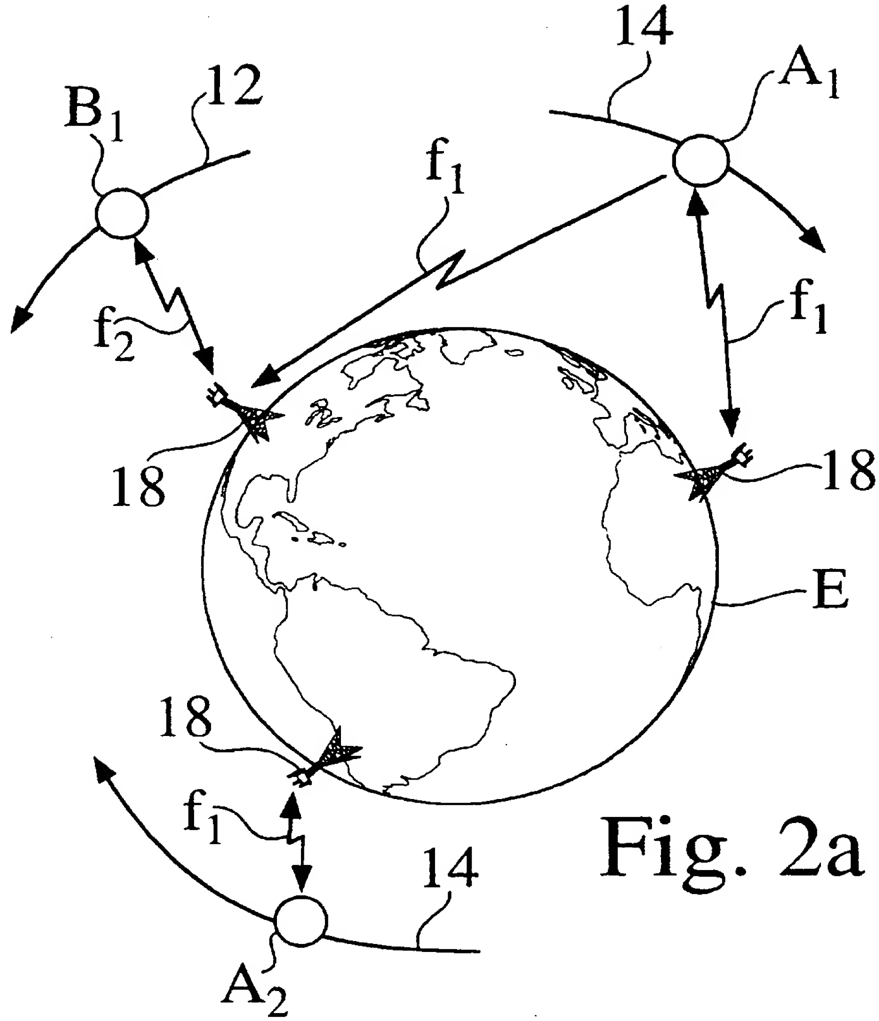
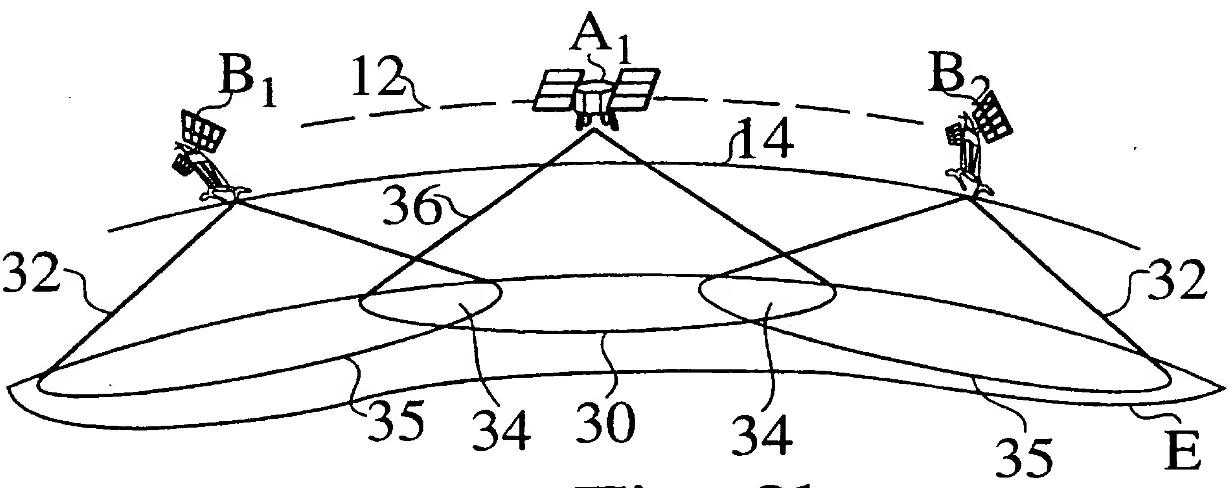

14
A_1
B_1
12
f_1
f_2
f_1
18
18
E
18
f_1
14
A_2

Fig. 2a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B_1
12
B_2
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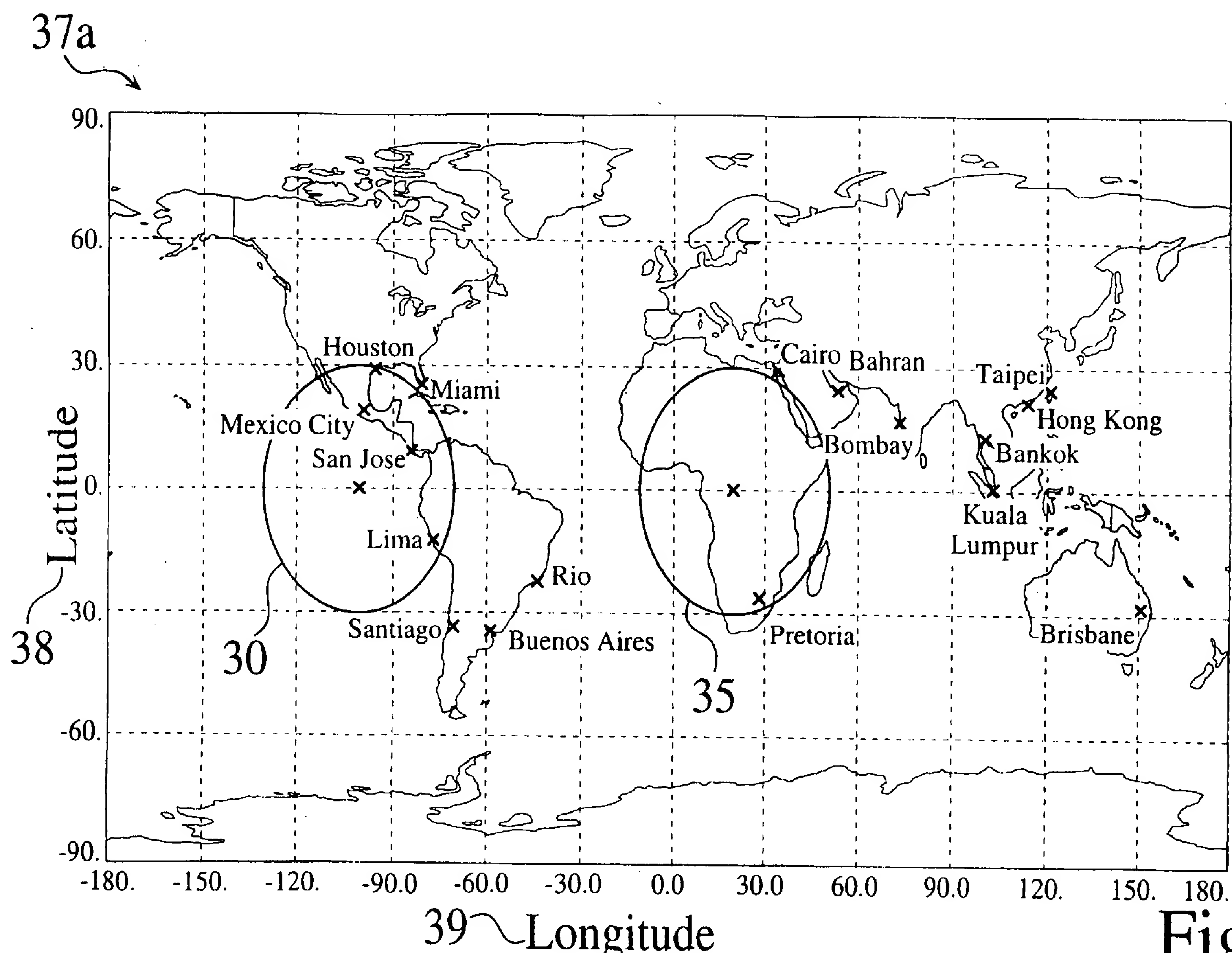
36
32
32
35
34
30
34
35
E

Fig. 2b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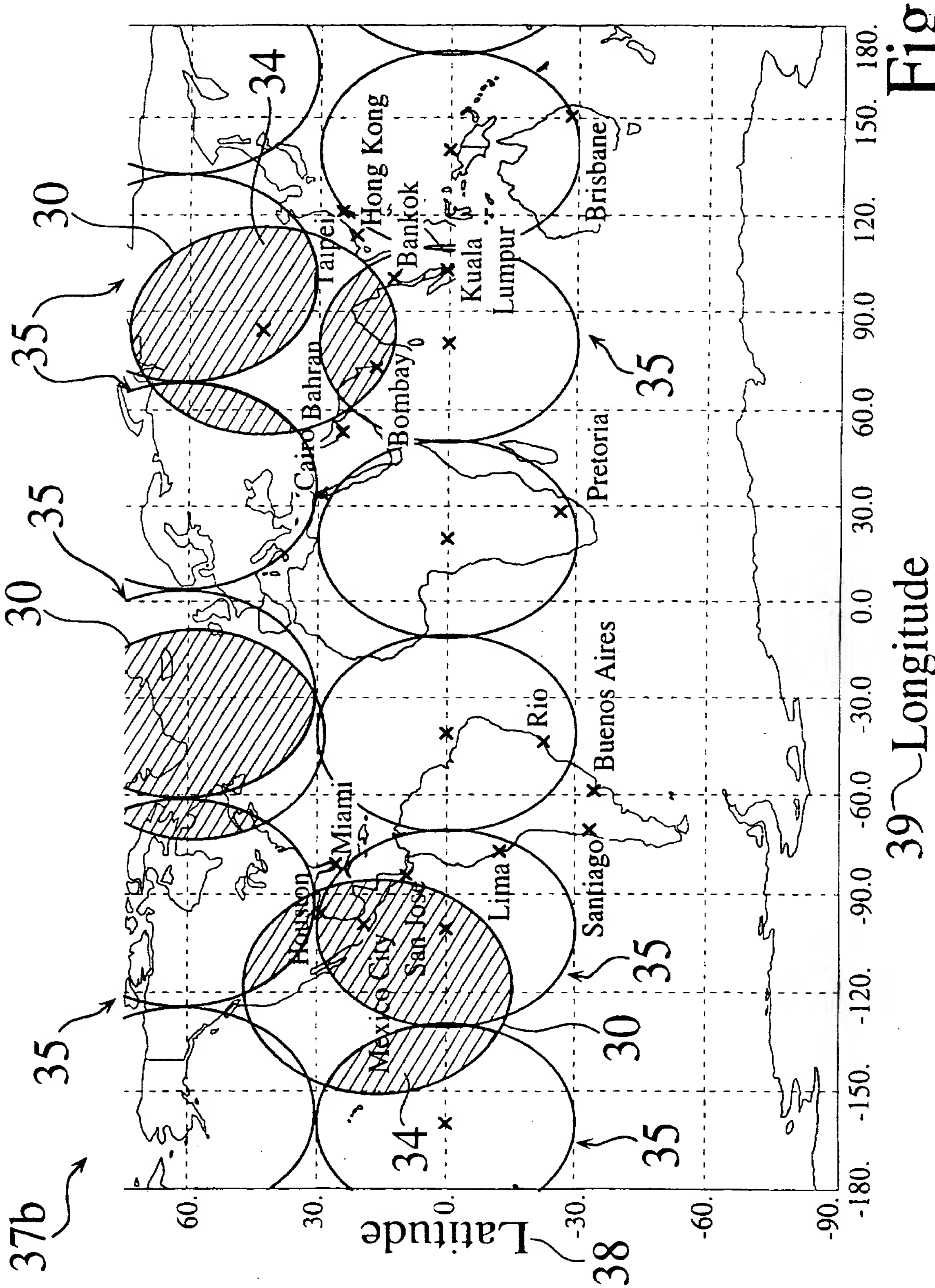
60.
30.
0.
-30.
-60.
-90.
Latitude
38
30
35
Houston
Miami
Mexico City
San Jose
Lima
Santiago
Rio
Buenos Aires
Cairo
Bahran
Bombay
Pretoria
Taipei
Hong Kong
Bankok
Kuala
Lumpur
Brisbane
-180.
-150.
-120.
-90.0
-60.0
-30.0
0.0
30.0
60.0
90.0
120.
150.
180.
39
Longitude

Fig. 3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Latitude
38
Longitude
39
60.
30.
0.
-30.
-60.
-90.
-180.
-150.
-120.
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60.0
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120.
150.
180.
30
34
35
Houston
Miami
Mexico City
San Jose
Lima
Santiago
Buenos Aires
Rio
Cairo
Bahran
Bombay
Taipei
Hong Kong
Bankok
Kuala Lumpur
Pretoria
Brisbane

Fig. 4

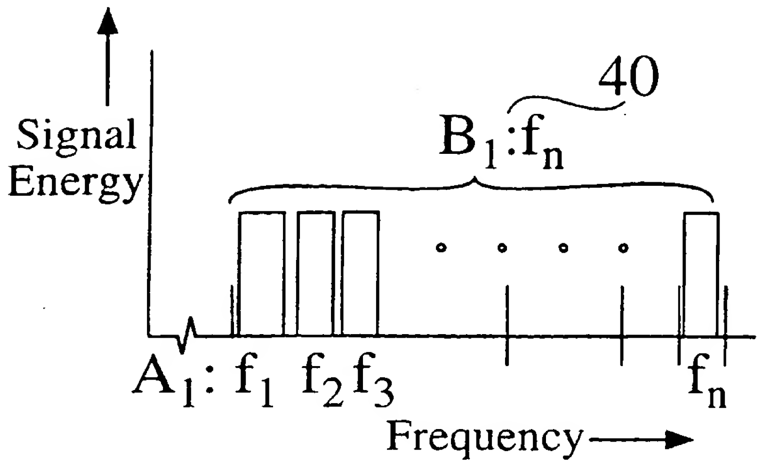

Fig. 5

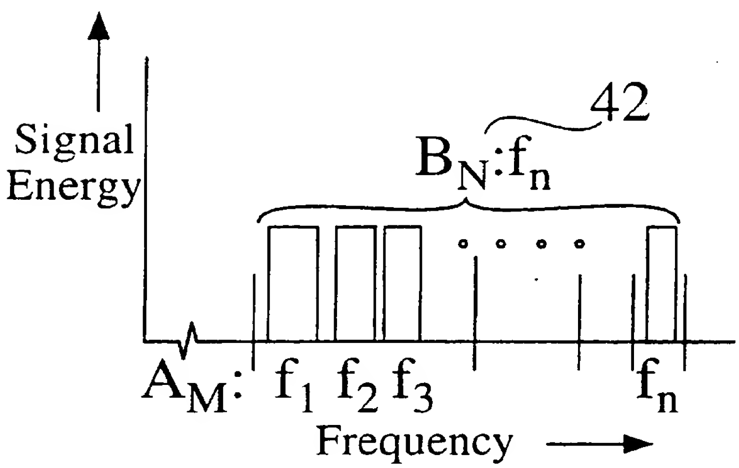

Fig. 6

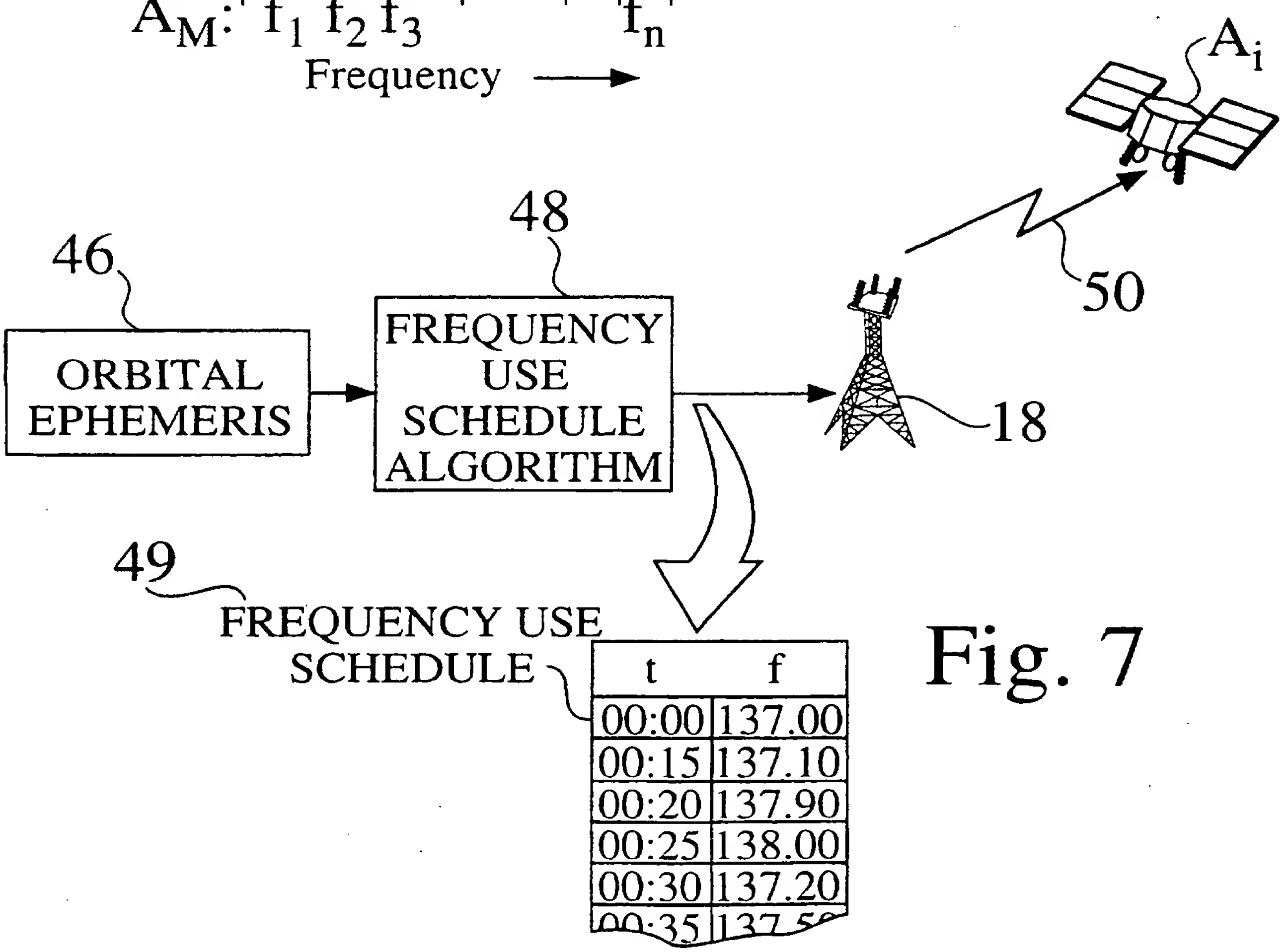

Fig. 7

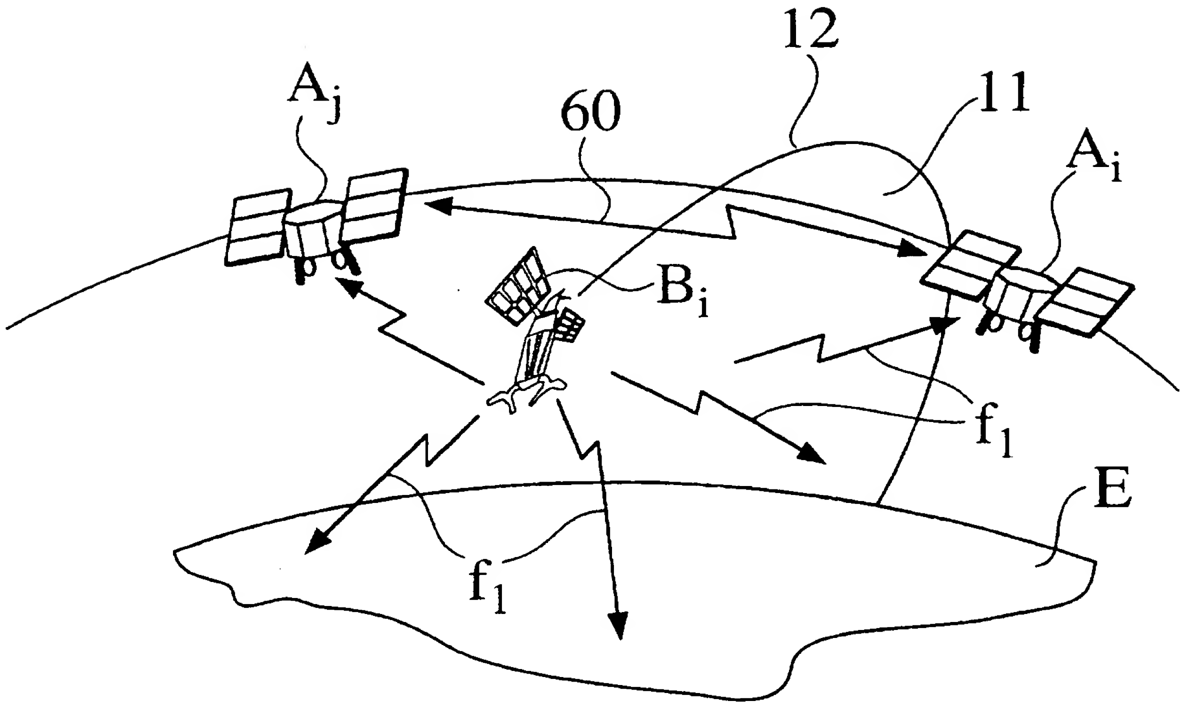

Fig. 8

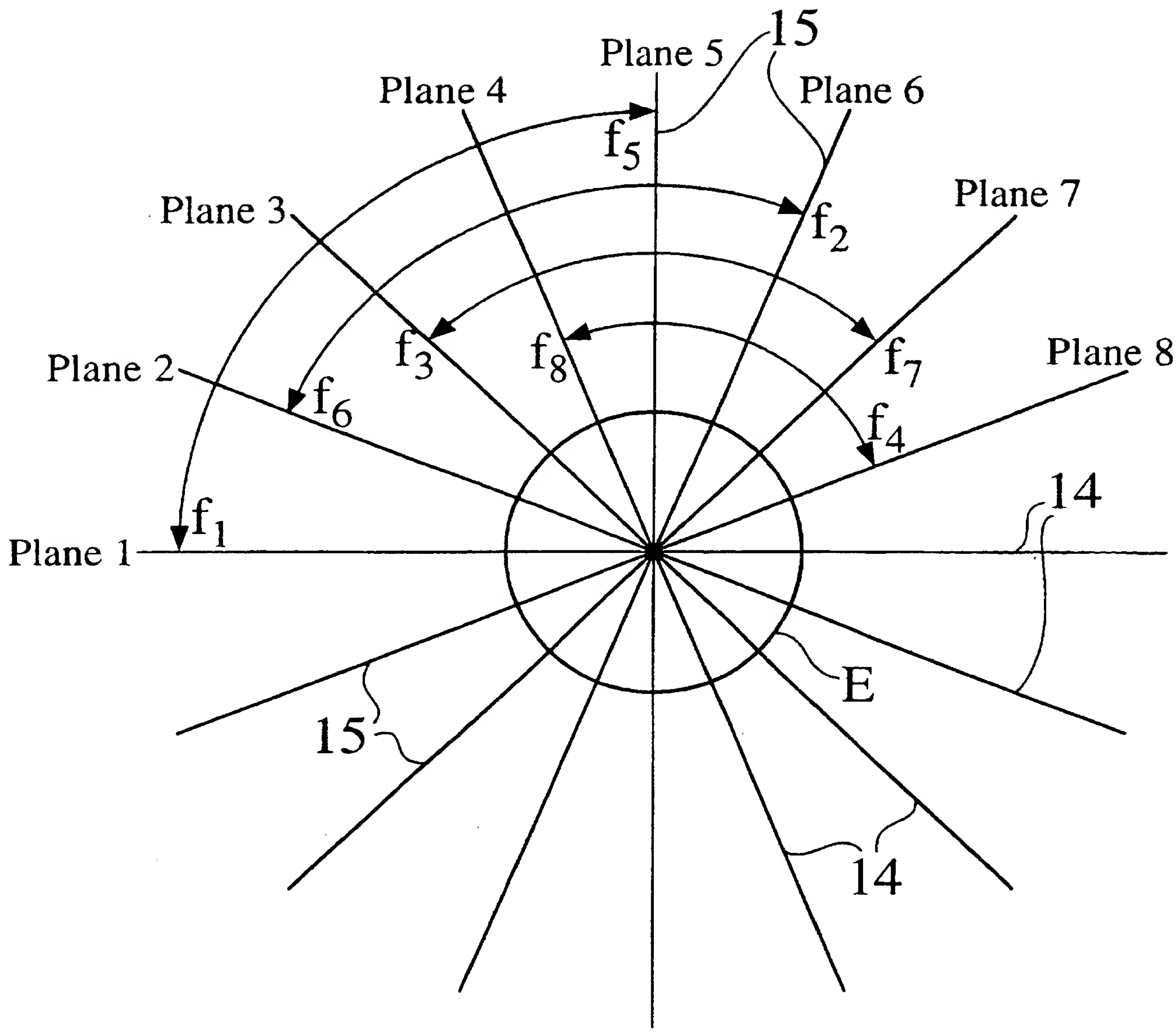
Plane 5
15
Plane 4
Plane 6
f_5
Plane 3
f_2
Plane 7
f_3
f_8
f_7
Plane 8
Plane 2
f_6
f_4
14
f_1
Plane 1
E
15
14

Fig. 9

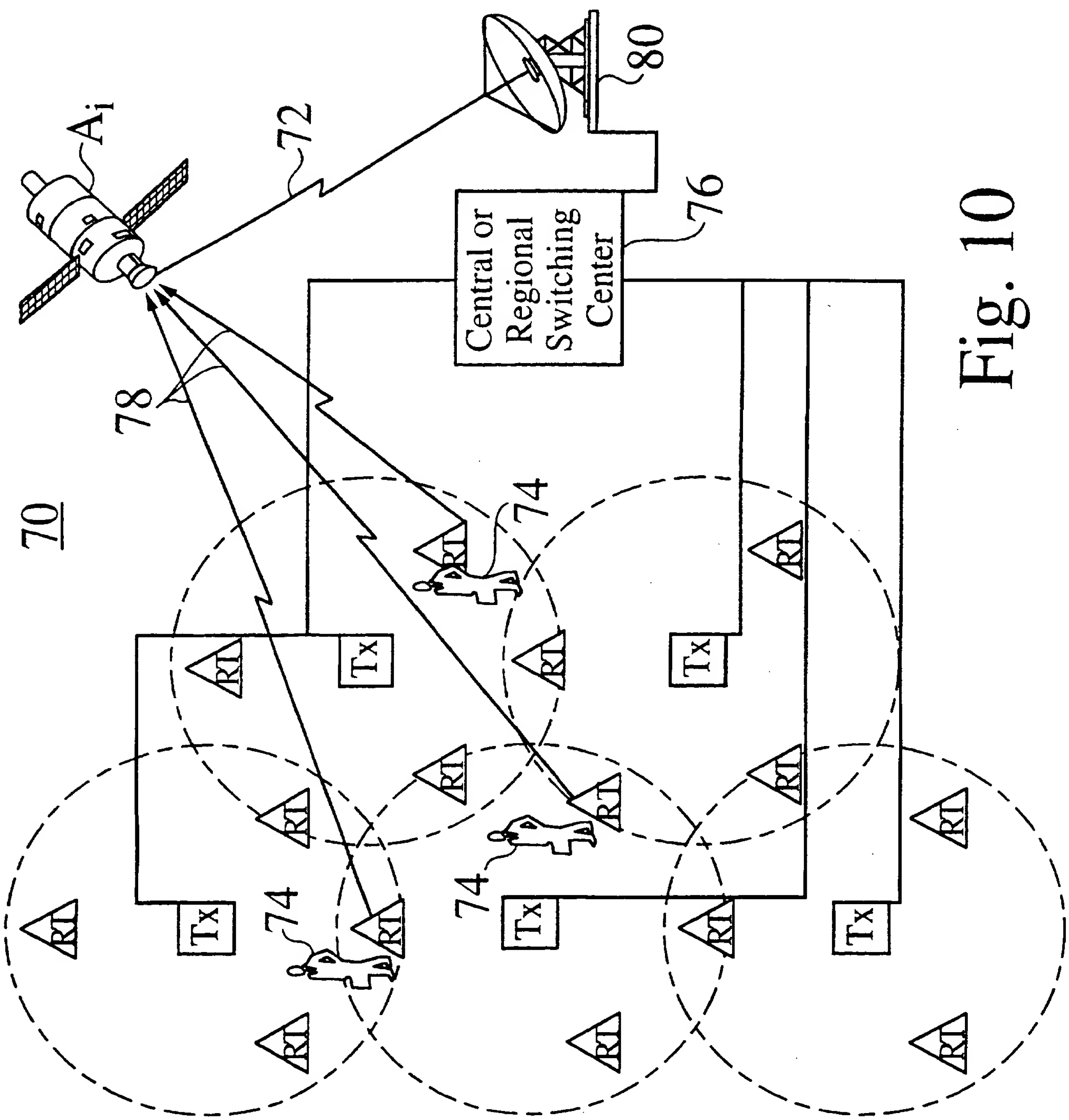
70
A_i
72
80
76
Central or Regional Switching Center
78
74
Tx
RT

Fig. 10

INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 97/14206

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04B7/185

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 720 308 A (AGENCE SPATIALE EUROPEENNE) 3 July 1996 see claims 1-21; figures 1-10 ---	1,11,18, 23
A	MIZUIKE T ET AL: "TRAFFIC MODELING AND FREQUENCY RESOURCE MANAGEMENT FOR MOBILE SATELLITE NETWORKS" 9TH. ITC SPECIALISTS SEMINAR: TELETRAFFIC MODELLING AND MEASUREMENT BROADBAND AND MOBILE COMMUNICATIONS, LEIDSCHENDAM, NOV. 7 - 9, 1995, no. SEMINAR 9, 7 November 1995, ROBERTS J W ET AL, pages 147-164, XP000683152 see page 155, line 19 - page 160, line 23 --- -/--	1,11,18, 23

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

1

Date of the actual completion of the international search	Date of mailing of the international search report
9 December 1997	17/12/1997
Name and mailing address of the ISA European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Authorized officer Bischof, J-L

Int ional Application No
PCT/US 97/14206

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	COHEN M ET AL: "FREQUENCY SHARING BETWEEN LEO SYSTEMS" PROCEEDINGS OF THE CONFERENCE ON TELECOMMUNICATIONS, MANCHESTER, APR. 18 - 21, 1993, no. CONF. 4, 18 April 1993, INSTITUTION OF ELECTRICAL ENGINEERS, pages 312-317, XP000473743 see page 313, left-hand column, line 6 - page 316, right-hand column, line 28	1,11,18, 23
X	WO 96 12356 A (LEO ONE) 25 April 1996	21,22
A	see claims 1-48; figures 1-25	1-20,23

1

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/US 97/14206

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 720308 A	03-07-96	FR 2729025 A	05-07-96
		CA 2166366 A	03-07-96
		CA 2193573 A	03-07-96
		EP 0771085 A	02-05-97
		JP 8265240 A	11-10-96
WO 9612356 A	25-04-96	AU 4128196 A	06-05-96
		CA 2201470 A	25-04-96
		EP 0787387 A	06-08-97
		US 5666648 A	09-09-97